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3RD WAVE ENGINEERING

PROGRAM MANUAL

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COMPUTER AIDED DATA ACQUISITION AND ANALYSIS SYSTEM FOR A CONDUCTION CALORIMETER

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P.O. BOX 13460 KANATA, ONTARIO CANADA K2K 1X6 (613) 592-4107

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EXECUTIVE SUMMARY

Conduction Calorimeters are used to study the evolution of heat during the hydration of cement. The experiments generally last 3 to 7 days during which the output of a temperature sensor in the calorimeter is continually recorded. The sensor data is differentiated twice to obtain information on the instantaneous rate of heat evolution and the rate of change in heat evolution. The total quantity of heat evolved is derived from an integration of the sensor output.

The large volume of data involved and the difficulties associated with accurate numerical integration and differentiation make Conduction Calorimetry an ideal candidate for Computer Aided Data Acquisition and Analysis.

The 3RD Wave Engineering Conduction Calorimeter Data Acquisition and Analysis System consists of Data Acquisition and Experiment Control hardware, known as the AUTO-GRAPH II, and Data Analysis software for an APPLE IIe. The system provides the following features:

1. Programmable data acquisition and control of the calorimeter experiment by the AUTO-GRAPH II, without connection to the host APPLE computer.

2. Electronic filing of experiment remarks, observations and data on APPLE disk files.

3. Communication of the entire sensor output history from the AUTO-GRAPH II to the APPLE computer for subsequent analysis.

4. Calculation,graphic display and filing of calorimeter calibration constants, instantaneous rate of heat production, rate of change of heat production and total heat produced.

The unique feature of the data acquisition and analysis system is the manner in which the difficult problem of differentiating numerical data is handled.

INTRODUCTION

Conduction calorimeters are used to study the hydration of hydraulic cements under nearly isothermal conditions. The hydrating cement produces temperature changes, in the order of 1 degree C, and the temperature sensor outputs are typically displayed on strip chart recorder over periods extending up to seven days. Determining the total heat evolved requires an integration of the temperature history and determining the instantaneous rate of heat evolution requires differentiation of the temperature history. The rate of change of heat evolution can provide further information on the kinetics of the reactions occuring during hydration. Determining this rate of change requires then a second differentiation of the conduction calorimeter output. The large volume of data produced and the difficulty of obtaining accurate differentials, especially when second derivatives are involved, makes cement hydration calorimetry an ideal candidate for Computer Aided Data Acquisition and Analysis.

The 3RD Wave Engineering Conduction Calorimeter Data Acquisition and Analysis System provides the following features:

1. At the start of each experiment the expected duration is entered into the AUTO-GRAPH II. Under the control of its own program the AUTO-GRAPH II will sense and store the sensor output of the calorimeter for the duration of the experiment. At the end of the experiment the AUTO-GRAPH II will activate a small heat source of known power in the calorimeter to provide information for calibration of the system.

2. After the start of the experiment remarks concerning the cement, any additives and the conditions of the test are entered, stored on the APPLE disk for future reference and use in performing the data analysis after completion.

3. At the end of the experiment the entire sensor output history, including the calibration is retrieved from the interface and filed on the computers disk system.

4. The analysis module of the program calculates the calibration constants of the calorimeter, instantaneous rate of heat evolution and the total heat evolved. All calculations are displayed on the monitor as a graph or numeric data and filed on disk. The user also has the option of printing a copy of all the graphs displayed on the monitor. The output for the graphs is a dot matrix printer and they show the resolution steps of the graphics screen. A better publication quality graph would be obtained with a plotter.

5. The instantaneous rate of heat evolution is differentiated to provide a history of the rate of change in heat evolution which is also displayed as a graph and filed on disk.

6. At any time the data file of experiment remarks, parameters and numeric results can be retrieved and printed.

Heat evolution in concrete is characterized by two and sometimes three rate peaks (ref. 1) and long periods of gradually decreasing heat evolution. This characteristic of concrete results in the conduction calorimeter temperature sensor output rising rapidly and then remaining constant or decreasing with a small slope over extended periods of time. The sensor output, with its large range of slope, must be differentiated to obtain quantitative measurements of the instantaneous rate of heat evolution. Differentiation by finite difference methods is always subject to significant error when small differences are employed to determine instantaneous rates. When it is neccessary to differentiate the result a second time to determine the rate of change the errors are compounded and the results quickly become meaningless.

To overcome the accuracy problem inherent with finite difference techniques the 3RD Wave Engineering Conduction Calorimeter Data Acquisition and Analysis System employs the following techniques to provide differentiated results of high accuracy.

1. The sensor output is sampled at a relatively high frequency, but the readings are recorded only when a change of specified magnitude has occurred. With this technique the recorded readings will be closely spaced in time when rapid changes are occurring and very widely spaced when the slope is small.

2. To determine the derivative of the results a quadratic curve, whose derivative can be precisely calculated, is fitted to the data points available within a preset time interval.

The total heat evolved by the concrete is determined by integration of the curve fitted to the sensor output.

The theory relating to the calibration of the calorimeter, the differentiation and integration of the heat evolution rate curves is presented in the final section.

The program guides the user by means of menu selection and prompts and to the extent possible analyses all user input for validity. Default values are provided for numeric entry required by the program or the user may overide these defaults with other inputs.

Before proceding further make a copy of the Conduction Calorimeter Disk provided, using the APPLE COPYA Program, and store the original in a safe place.

OPERATION OF THE AUTO-GRAPH II

It is important that the following initial conditions be observed before starting the AUTO-GRAPH II.

1. Power to the AUTO-GRAPH II is off.
2. The cassette recorder is off.
3. The calibration power supply is off.
4. The calorimeter sensor is connected.

To start operation of the AUTO-GRAPH II proceed as follows:

1. Turn power on to the AUTO-GRAPH II with the switch located at the rear left of the unit.
2. Insert the program cassette in the recorder, label side up, and rewind the tape.
3. Load the program by depressing and latching the PLAY key and enter the following at the AUTO-GRAPH II keyboard:

   Press <BREAK>

   Type CLOAD <ENTER>

   The recorder will stop automatically after the program is loaded but depress the STOP key of the recorder to unlatch the PLAY mode.

4. After loading the program enter the following:

   Press <BREAK>

   Type RUN <ENTER>

   If the program load was successful the display will read;

   ```
   STANDBY                          TIME 00:00:00
   PLEASE ENTER THE DURATION IN HOURS
   ```

   If the program is not successfully loaded repeat the procedure from step 3.

5. After the experiment duration is entered the display will read;

   PRESS <ENTER> TO START

The calibration power supply should now be turned on. The experiment may be "STARTED" at any time whether the cement sample is in the calorimeter or not. It is recommended that the start be entered when water is first added to the cement thereby providing a true zero to the time base. No sensor output can be expected until the cement sample is inserted in the calorimeter but if this happens quickly after the initial mixing of water only a small amount of heat will be lost from the sample because the sample itself has a heat capacity and the heat transfer rate from the sample bag in air will be less than the heat transfer rate when the sample is immersed in oil in the calorimeter. It is important to ensure that the calorimeter sensor be connected to the AUTO-GRAPH II before the START command is entered.

6. Any other operations required at the AUTO-GRAPH II will be prompted by the display.

SCREEN 1

****

CONDUCTION CALORIMETER DATA ACQUISITION AND ANALYSIS PROGRAM
BY
3RD WAVE ENGINEERING

****

MENU

1. SET UP CONDUCTION CALORIMETER EXPERIMENT
2. MONITOR EXPERIMENT PROGRESS
3. READ EXPERIMENT DATA
4. CALCULATE HEAT EVOLUTION RATE AND TOTAL HEAT
5. CALCULATE RATE OF CHANGE IN HEAT EVOLUTION
6. PRINT COPY OF EXPERIMENT DATA FILE
9. QUIT

PLEASE ENTER SELECTION :

OPERATION OF THE CONDUCTION CALORIMETER ANALYSIS PROGRAM

General Information

The Conduction Calorimeter Program Disk is placed in Drive 1 of the APPLE IIe. Each completed and analysed experiment will place four data files on the disk in Drive 2. The file name is composed of a prefix of up to 12 characters entered by the user prior to the beginning of the experiment and a suffix inserted by the program as follows:

1. File Name.C - file containing all user input of experiment remarks and data at the beginning of each new experiment. After completion of data processing the file will also contain the calorimeter calibration constants and the total heat evolved during the experiment.

2. File Name.E - file containing the calorimeter sensor output history.

3. File Name.Q - file containing the calculated heat evolution rate.

4. File Name.DQ - file containing the calculated rate of change in heat evolution.

Start Up

To start the operation of the 3RD Wave Engineering Conduction Calorimeter Data Aquisition and Analysis Program procede as follows:

1. Insert the Program Disk in Drive 1 of the APPLE and turn power on to the system.

2. Insert an initialized Data Disk in Drive 2.

3. After the disks are in place type RUN CONCAL <RETURN>.

Menu

A brief interval after typing RUN CONCAL the APPLE monitor will display the program menu of SCREEN 1. After the menu selection the screen will be cleared and will then display;

PLEASE WAIT, READING FILES

Each of the menu items is described in more detail in what follows.

SCREEN 2

CONDUCTION CALORIMETER DATA

1. FILE NAME (MAX 12 CHARACTERS) ?

2. CEMENT - ORIGIN ?

3. - BATCH ?

4. ADDITIVE - ORIGIN ?

5. - TYPE ?

6. - TREATMENT ?

7. - FINENESS ?

8. - % REPLACEMENT ?

DO YOU WISH TO MAKE ANY CHANGES <Y or N> ? LINE NUMBER TO BE CHANGED ?

CTRL X TO RESTART AN ENTRY OR CORRECTIONS CAN BE MADE AFTER DATA ENTERED

Set Up Conduction Calorimeter Experiment

The first half of the Experiment Set Up is illustrated in SCREEN 2.

The following applies to the entry of data on SCREEN 2:

1. The delete or backspace keys may be used to edit any entry, CTRL X may be used to restart any entry or the user is given an opportunity to re-enter any data once all questions on the screen have been answered.

2. The program must be supplied with a file name before it will accept further data. The file name must begin with an upper case letter, cannot contain a comma, a period, or a control character not echoed on the screen. The file name is limited to 12 characters including spaces. APPLE DOS will accept up to 30 characters but for this application the file name is limited to 12 characters to reduce the possibility of entry errors later in the program.

3. All the remainder of the entries of SCREEN 2 will accept any character that can be typed from the APPLE keyboard and are limited in lenght to 35 characters including spaces. Entering carriage return, without any other entry will will record no comment.

4. After all the questions of SCREEN 2 have been answered the question regarding changes will appear on the screen. The question can only be answered Y(es) or N(o), and if Y(es) the line number question will appear. The line number question will accept as input only those numbers appearing on the screen.

5. To exit from SCREEN 2 the question concerning changes must be answered with an N(o) when it first appears or after all changes have been made.

SCREEN 3

CONDUCTION CALORIMETER DATA

9. WEIGHT OF CEMENT SAMPLE <30 g> ?

10. WEIGHT OF OIL <50 g> ?

11. BATH TEMPERATURE <25 C> ?

12. EXPERIMENT DURATION <72 h> ?

13. MAX SENSOR OUTPUT <Max 10 mV> ?

14. CALIBRATION POWER <0.1 W> ?

DO YOU WISH TO MAKE ANY CHANGES <Y or N> ? LINE NUMBER TO BE CHANGED ?

PRESS RETURN TO ACCEPT <DEFAULT> VALUE

CTRL X TO RESTART AN ENTRY OR CORRECTIONS CAN BE MADE AFTER DATA ENTERED

The remainder of the data entry takes place on SCREEN 3 and the following criteria apply.

1. The delete or backspace keys may be used to edit any entry or CTRL X may be used to restart any entry or the user is given an opportunity to re-enter any data once all questions on the screen have been answered.

2. The entries of SCREEN 3 are all supplied with <DEFAULT> values which may be accepted pressing <RETURN>.

3. In the event that values other than the <DEFAULT> values are required in SCREEN 3 they are entered at the time the question is asked. The program will only accept numeric values other than zero.

4. Any entry not complying with the criteria described above will be rejected and the bell will sound requesting re-entry.

5. After all the questions of SCREEN 3 have been answered the questions regarding changes will appear. When no further changes are required the program will exit SCREEN 3 and return to the menu of SCREEN 1.

The remarks file, and all other data files, are "locked" after writing to disk to guard against accidental erasure. If for any reason it becomes necessary to change data in the remarks file after it has been created it is best to recreate the file entirely using the following procedure:

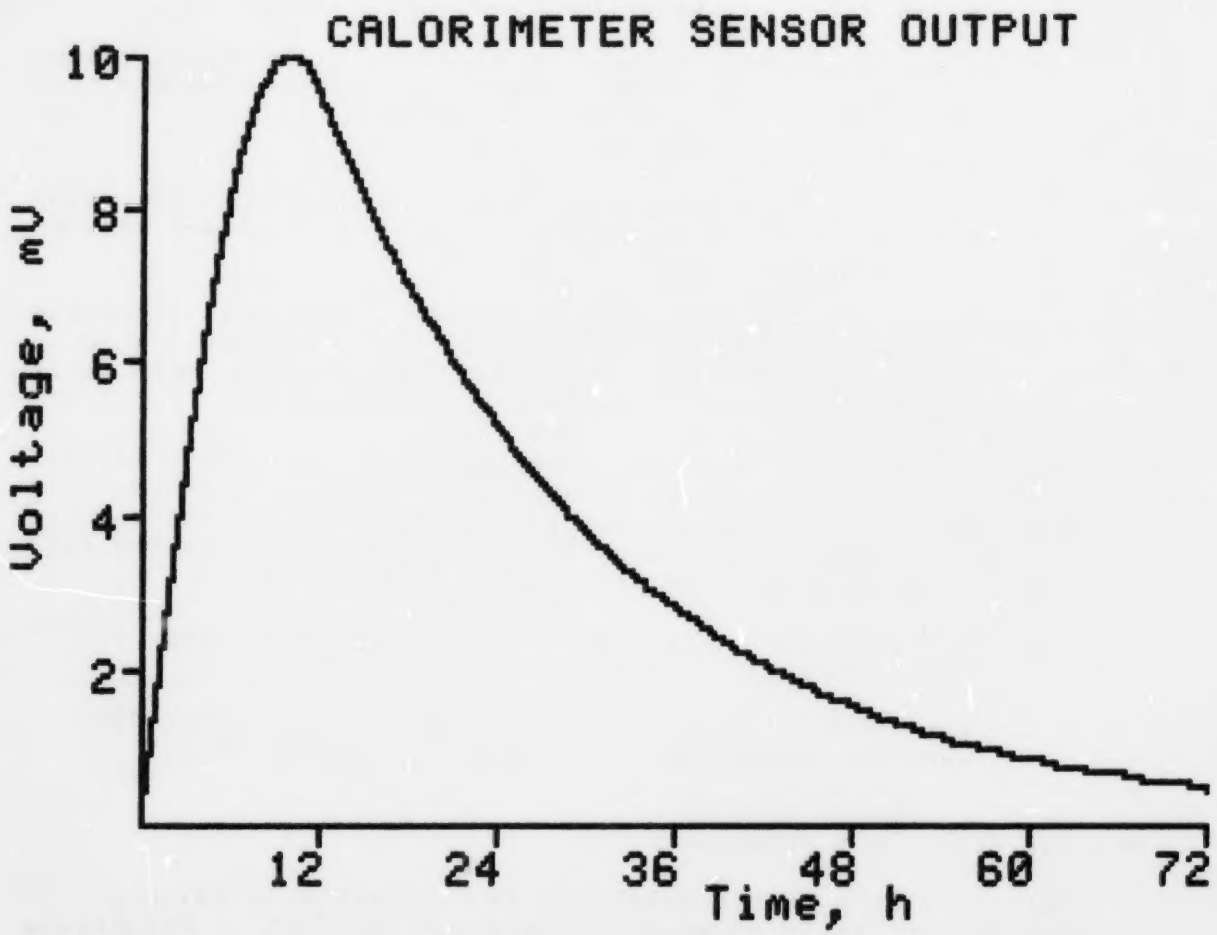
1. Exit from the calorimeter Program and then type, UNLOCK File Name.C

2. Type RUN CONCAL, select menu item 1 and re-enter data as described above, with the necessary corrections.

Monitor Experiment Progress

This menu item is not available in the current version of the program and is included only for future expansion. Requesting this menu item will result in an error message. The AUTO-GRAPH II will always display the current sensor output reading and if a detailed history is required during the experiment it is suggested that a strip chart recorder be attached to the sensor output.

SCREEN 4


CALORIMETER SENSOR OUTPUT
Voltage, mV
10
8
6
4
2
12
24
36
48
60
72
Time, h

Read Experiment Data

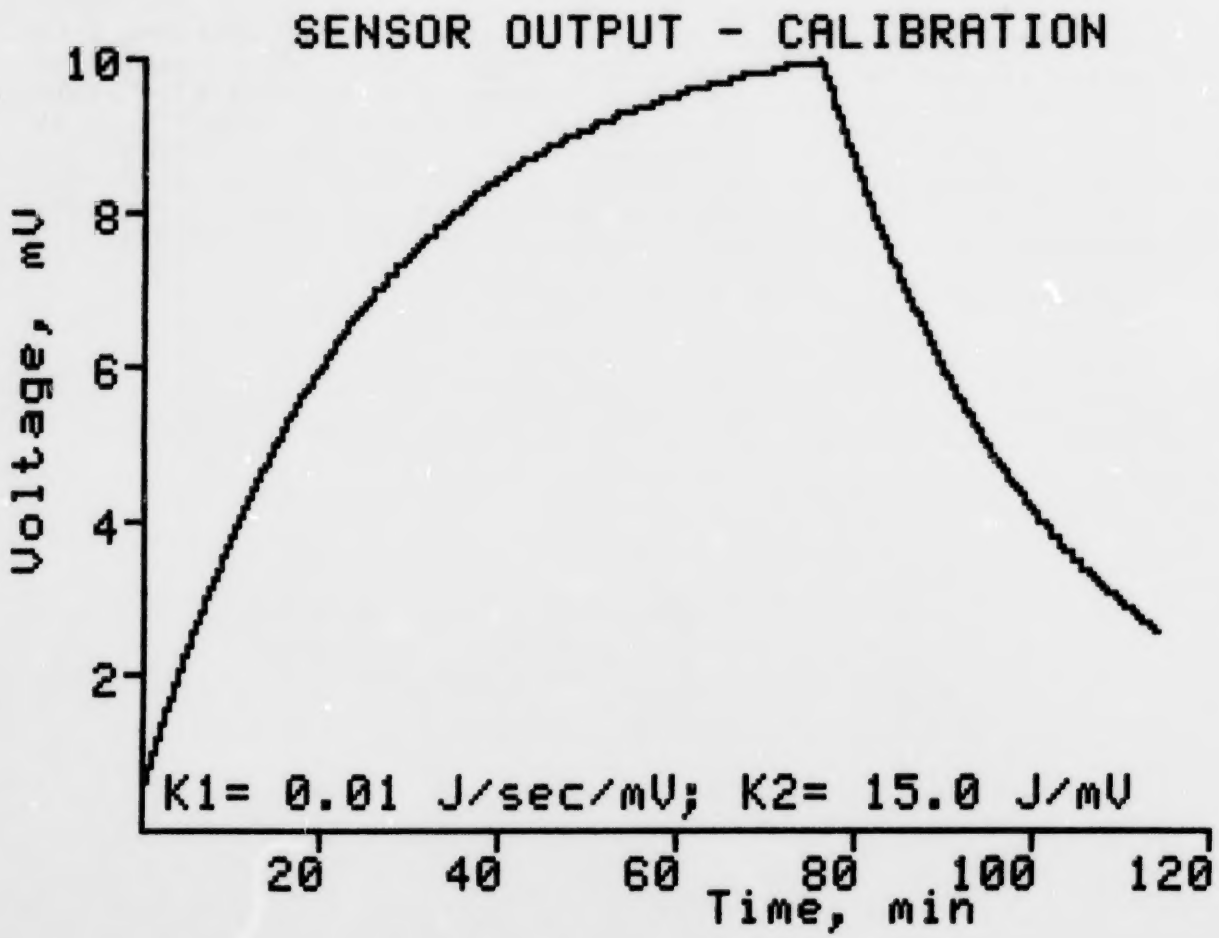
After completion of the experiment, which will be indicated by the display of the AUTO-GRAPH II, the data is transferred to the APPLE by first selecting Menu Item 3. The APPLE will request entry of the experiment file name;

ENTER THE EXPERIMENT FILE NAME :

After a short interval the APPLE screen will be cleared and will display "?" and a cursor. At this point press <P> on the AUTO-GRAPH II keyboard. Communication of data will be indicated by a series of numbers scrolling up the APPLE screen. Upon completion of data communications the APPLE program will automatically begin display of the sensor output history as shown in SCREEN 4. At the end of the experiment history, but before the display of the calibration phase, a two tone bell will sound and program execution will halt providing an opportunity to study the graph. Pressing any key will result in the graph being replaced by;

DO YOU WANT COPY OF THE GRAPH <Y or N> ?

SCREEN 5


SENSOR OUTPUT - CALIBRATION
Voltage, mV
10
8
6
4
2
K1= 0.01 J/sec/mV; K2= 15.0 J/mV
20
40
60
80
100
120
Time, min

The program will then procede to display the calibration curve, as illustrated in SCREEN 5, and to calculate the calibration coefficients. Again the bell will sound at the completion of the calculations and pressing any key will replace the graph with;

DO YOU WANT A COPY OF THE GRAPH <Y or N> ?

DO YOU WISH TO CONTINUE WITH THE DATA ANALYSIS <Y or N> ?

If the latter question is answered Y(es) the program will proceed to the next menu item automatically, otherwise it will return to the menu. In either case the experiment sensor output file will be written to the disk and will be available for subsequent processing.

If errors are made in file name entry error messages as described later will be displayed.

Calculate Heat Evolution Rate and Total Heat

This menu item selects the calculation of the instantaneous rate of heat evolution and the integration of the heat evolution rate to provide total heat evolved by the concrete sample during the experiment. It may be entered entered directly at the beginning of a session or by proceeding to it from the prior menu item. The operation of the program will proceed as follows:

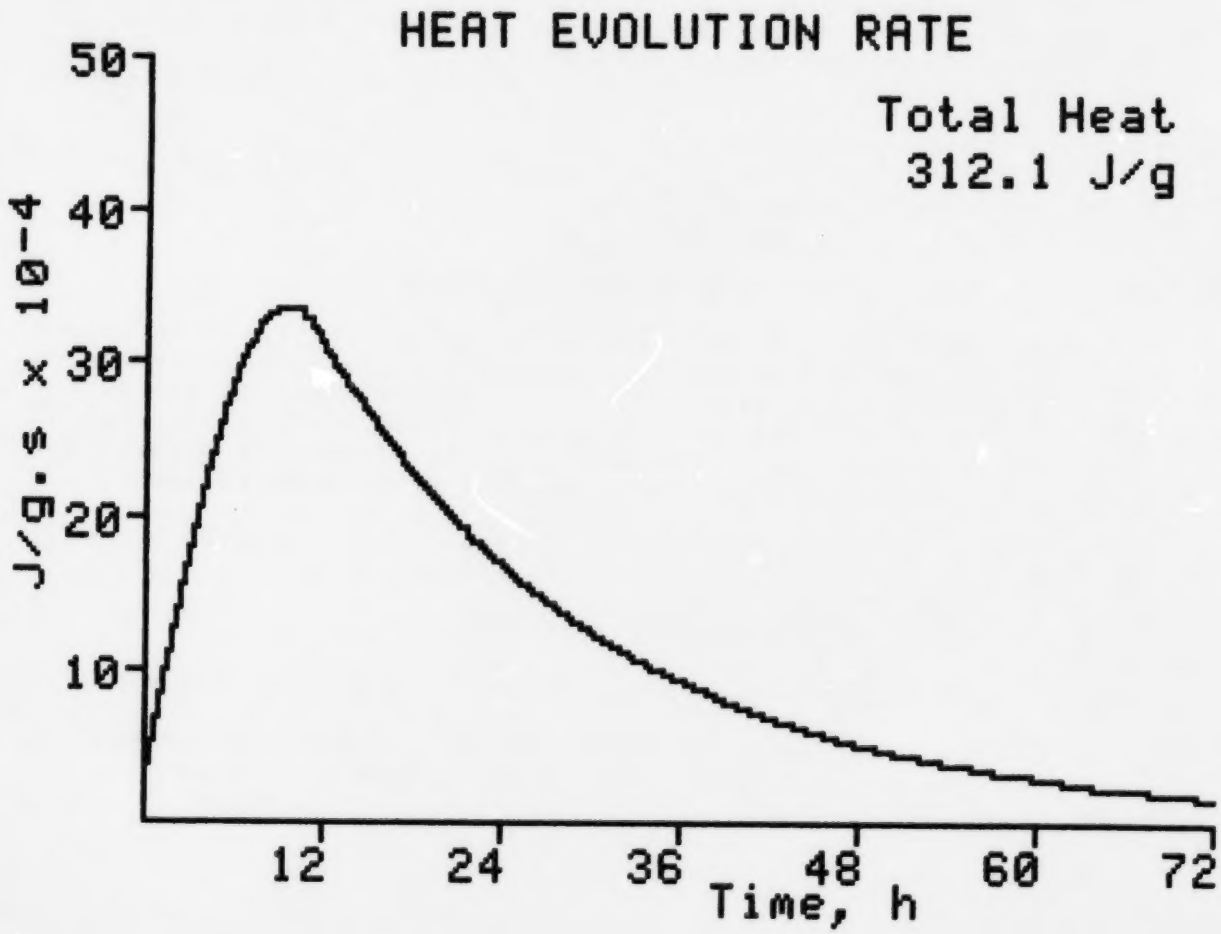
1. If entered directly from the menu the program will request the experiment file name;

   ENTER THE EXPERIMENT FILE NAME :

   and read the experiment sensor output file from disk.

2. The program will then calculate an approximate maximum heat evolution rate for graph scaling purposes.

SCREEN 6


HEAT EVOLUTION RATE
Total Heat
312.1 J/g
J/g.s x 10-4
50
40
30
20
10
12
24
36
48
60
72
Time, h

3. The Heat Evolution Rate will be displayed on the APPLE as illustrated in SCREEN 6 and the results of the calculation will be written to a disk file.

4. The two tone bell will signal the end of the calculation and halt program execution. Pressing any key will resume the program and provide an opportunity to print a copy of the graph displayed and to continue or terminate the session.

Calculate Rate of Change In Heat Evolution

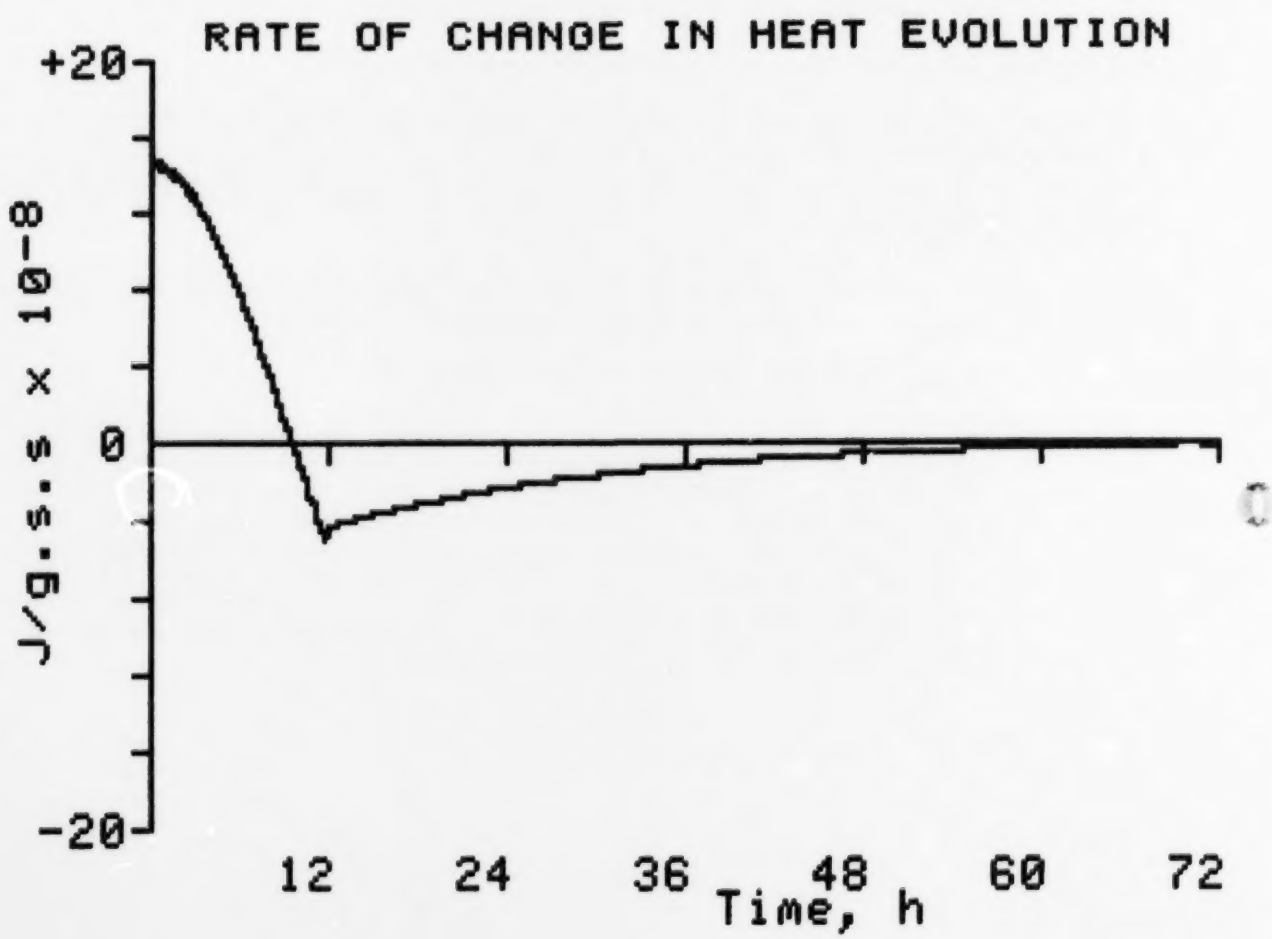
The calculation of the Rate of Change in Heat Evolution may be entered either through menu selection at the beginning of a session or by proceeding to it from the prior calculation of the instantaneous Rate of Heat Evolution. Program operation will proceed as follows:

1. If entered directly from the menu the program will request entry of the experiment file name;

   ENTER THE EXPERIMENT FILE NAME :

2. The program will then read the Heat Evolution Rate file from the disk and calculate an approximate maximum rate of change in Heat Evolution for graph scaling purposes. The graph will not display the very large rates of change usually encountered at the beginning of hydration so that subsequent detail in the rate of change will be more apparent. However all the calculations from the beginning of the experiment are performed and recorded on the disk file for later examination.

SCREEN 7


RATE OF CHANGE IN HEAT EVOLUTION
+20
0
-20
J/g.s.s x 10-8
12
24
36
48
60
72
Time, h

3. The Rate of Change in Heat Evolution will be displayed on the APPLE as illustrated in SCREEN 7 and the results of the calculation are written to a disk file.

4. The two tone bell will signal the end of the calculation and halt program execution. Pressing any key will resume the program and provide an opportunity to print a copy of the graph displayed. At the end of this item the program will redisplay its' menu.

Print Copy of Experiment Data File

Selection of this menu item at any time after the entry of the Set Up Data will produce a listing of the data entered. If the item is selected after the completion of all data analysis the listing will also include the Calibration Constants and the Total Heat Evolved during the experiment as illustrated in Table 1. The only entry required is the file name;

ENTER THE EXPERIMENT FILE NAME :

ERROR MESSAGES

Set Up Conduction Calorimeter Experiment

If an effort is made to enter invalid data, for example a comma, a period or a non printing character in a file name, the APPLE will sound a bell and not echo the invalid input on the screen. A similar condition will result from the entry of "0" for numeric data or a line number to be changed that is not present on the screen. No other error message will be displayed and the user need only proceed to enter data correctly.

If a file name that has been previously used on the disk in drive 2 is re-entered the program will display an error message, the disk catalog and prompts suggesting corrective action as follows:

File Name - FILE NAME PREVIOUSLY USED

VOLUME 254

File Name.C
File Name.E
File Name.Q
File Name.DQ

DO YOU WANT TO CHANGE DISKS <Y or N> ?

INSERT THE CORRECT DISK IN DRIVE 2 AND PRESS RETURN TO CONTINUE

DO YOU WANT TO CHANGE THE FILE NAME <Y or N> ?

PRESS <RETURN> TO RETURN TO THE MENU

Each prompt wil appear only after the prior one has been responded to and only if appropriate to the reponse. If the disk or the file name are not changed the program will abort data entry without writting a file to disk.

Read Experiment Data

A system error causing the transmission of non numeric data during the data transfer from the AUTO-GRAPH II to the APPLE will result in an error message at the end of data transmission;

TRANSMISSION ERROR - PLEASE RESTART AS FOLLOWS

1. PRESS ANY KEY ON THE APPLE
2. PRESS <P> ON THE AUTO-GRAPH II

Analysis Functions (Menu Items 3 - 5)

Incorrect entry of file names during the data analysis will result in the following error messages:

File Name - EXPERIMENT SET UP FILE NOT FOUND

File Name - SENSOR OUTPUT DATA ALREADY PROCESSED

File Name - SENSOR OUTPUT FILE NOT FOUND

File Name - HEAT EVOLUTION DATA ALREADY ANALYSED

File Name - HEAT EVOLUTION DATA FILE NOT FOUND

File Name - RATE OF CHANGE OF HEAT EVOLUTION ALREADY ANALYSED

Each error message will be accompanied by the data disk catalog and prompts for remedial action as follows:

VOLUME 254

File Name.C
File Name.E
File Name.Q
File Name.DQ

DO YOU WANT TO CHANGE DISKS <Y or N> ?

INSERT THE CORRECT DISK IN DRIVE 2 AND PRESS RETURN TO CONTINUE

DO YOU WANT TO CHANGE THE FILE NAME <Y or N> ?

DO YOU WANT TO THE NEXT DATA PROCESSING STEP <Y or N> ?

PRESS <RETURN> TO RETURN TO THE MENU

As previously, each prompt is displayed only after the prior one has been answered and the selection of prompts displayed is appropriate to the response and the error condition.

Print Copy of Experiment Data File

Incorrect file name entry will result in;

File Name - EXPERIMENT SET FILE NOT FOUND

The disk catalog and prompts will be similar to the examples cited above.

Other Error Messages

If the program disk is inadvertently removed from Drive 1 during the processing of data the program will display;

PROGRAM FILES NOT FOUND

VOLUME 254

(File Catalog of Drive 1)

DO YOU WANT TO CHANGE DISKS <Y or N> ?

INSERT THE CORRECT DISK IN DRIVE 1 AND PRESS RETURN TO CONTINUE

PRESS <RETURN> TO RETURN TO THE MENU

If a disk becomes full during a data write operation the APPLE will display;

DATA DISK FULL
PLEASE COPY FILES ALREADY PROCESSED TO A NEW DISK
AFTER COPYING RESTART PROCESSING AT THE CURRENT ITEM

PRESS <RETURN> TO RETURN TO THE MENU

The copy operation is accomplished using the APPLE FILEM program (on the System Master Disk) after return to the menu and an exit from the Conduction Calorimeter Program. FILEM will require the entry the complete file name, including the suffix added by the Calorimeter program, as follows:

1. File Name.C - Remarks and data
2. File Name.E - Sensor output
3. File Name.Q - Heat evolution rate
4. File Name.DQ - Rate of change in heat evolution

All other program or system errors are indicated by;

ERROR NUMBER " " IN LINE NUMBER " "

PRESS <RETURN> TO RETURN TO THE MENU

Consult your APPLE manual for the Error Codes.

CONDUCTION CALORIMETER THEORY

Calibration

The rate of heat evolution in a Conduction Calorimeter at any given time according to J.A. Forrester (Ref. 1) is

$$q = K_1 E + K_2 dE/dt \tag{1}$$

where q is the rate of heat evolution, E is the sensor output and K_1 and K_2 are constants. At the end of each experiment, when the rate of heat evolution is low and nearly constant over short periods of time, a small heater of known power is activated for a time sufficient to raise the sensor output to near its full scale output and then turned off. The sensor output during this calibration phase is illustrated in Figure 1 and its equation is

$$q_c + q_s = K_1 E + K_2 dE/dt \tag{2}$$

where q_c and q_s are the rates of heat evolution of the calibration heater and the residual heat rate of the sample. If the change in heat evolved by the sample is insignificant during the calibration then q_s can be replaced by

$$q_s = K_1 E_o \tag{3}$$

where E_o is the sensor output at the beginning of calibration. Substitution of (3) into (2) and integration during the time the calibration heater is on yields the equation

$$K_1 \int_{t_o}^{t_t} (E - E_o)dt + K_2(E_t - E_o) = q(t_t - t_o) \tag{4}$$

Integration during the period of time after the calibration heater has been turned off yields the equation

$$K_1 \int_{t_b}^{t_e} (E - E_o)dt + K_2(E_e - E_t) = 0 \tag{5}$$

Simultaneous solution of Equations (4) and (5) the yields values of the calibration constants.

Differentiation Procedure

To determine the instantaneous rate of heat evolution from

Equation (1) requires that the sensor output as a function of time be differentiated. Numerical differentiation, by finite difference methods, is merely the subtraction of successive sensor output readings and division by the time interval between them. Errors in sensor readings resulting from instrument inaccuracy, electrical noise and the finite resolution of the recording electronics can be a significant portion of the the small differences in readings between successive samples. This will result in significant error in the differential.

As mentioned earlier, a further differentiation of the rate of heat evolution is also required, implying a second differentiation of Equation (1). Any errors introduced by the first differentiation will be vastly magnified by the second differentiation. To overcome this problem the procedure adopted is as follows:

1. The calorimeter sensor output is sampled rapidly but data points are recorded only when a change between successive readings exceeds 1 part in 256 of the full scale sensor output. With this method frequent data points are collected when the sensor output is changing rapidly during periods of rapid change in heat output and infrequent points are collected when the rate of change in heat output is small.

2. The analysis program performs a least squares fit of a second order polynomial to adjacent data points within a preset time span of the point for which the derivative is being calculated. The minimum number of points used for the curve fit is 3 regardless of the time span.

The equation of the polynomial and its derivative are

$$y = k_0 + k_1 x + k_2 x^2 \tag{6}$$

$$dy/dx = k_1 + k_2 x \tag{7}$$

and the curve fitting is illustrated in Figure 2.

The equation of the curve with the least squares fit, when expressed in matrix notation is

$$[A] = [k][B] \tag{8}$$

where

$$[A] = \begin{bmatrix} n & \Sigma x & \Sigma x^2 \\ \Sigma x & \Sigma x^2 & \Sigma x^3 \\ \Sigma x^2 & \Sigma x^3 & \Sigma x^4 \end{bmatrix}$$

and

$$[k] = \begin{bmatrix} k_o \\ k_1 \\ k_2 \end{bmatrix} \quad , \quad [B] = \begin{bmatrix} \Sigma y \\ \Sigma xy \\ \Sigma x^2 y \end{bmatrix}$$

The matrix equations are solved by the Gauss-Jordan Elimination Method, with Normalization (Ref 2), to yield the constants of the polynomial and hence its derivative.

The minimum time span, to either side of the point for which the first derivative of the sensor output is being calculated, is 60 seconds. To provide additional smoothing for the second derivative the time span is increased to 270 seconds.

Integration Procedure

The total heat evolved by the cement sample is the integral of the instantaneous heat evolution rate

$$\int_o^t q \, dt = K_1 \int_o^t E \, dt + K_2(E - E_1) \qquad (9)$$

where E_1 is the calorimeter sensor output at the beginning of the experiment. The integral of E required in Equation (9) is obtained by integrating the second order polynomial of Equation (6), between adjacent data points, and summing all the values thus obtained to produce the integral over the time span of the experiment. The numerical integration procedure is thus similar to the well known Simpson's Rule of integration.

Figure 1. Sensor Output - Calibration

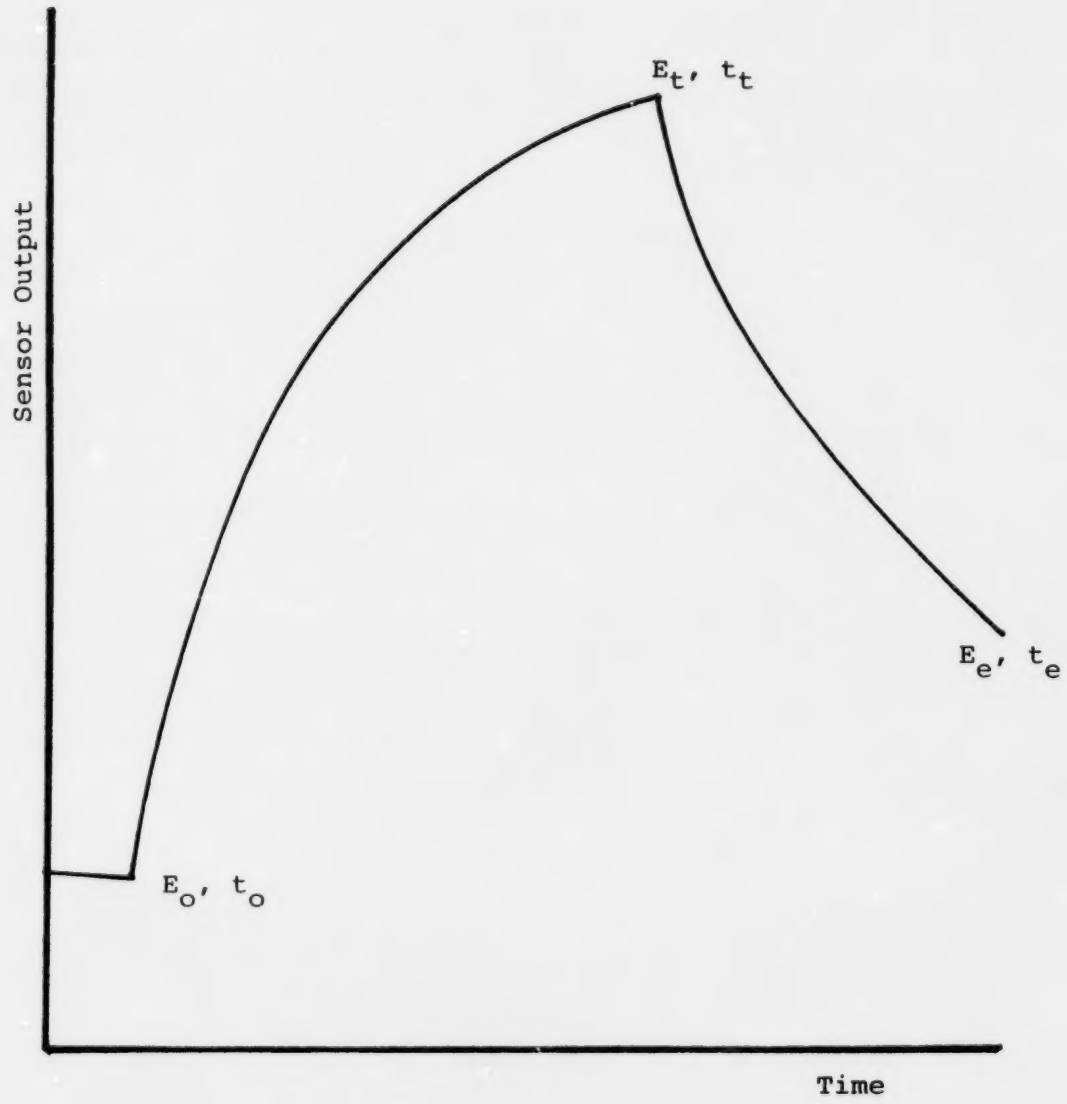
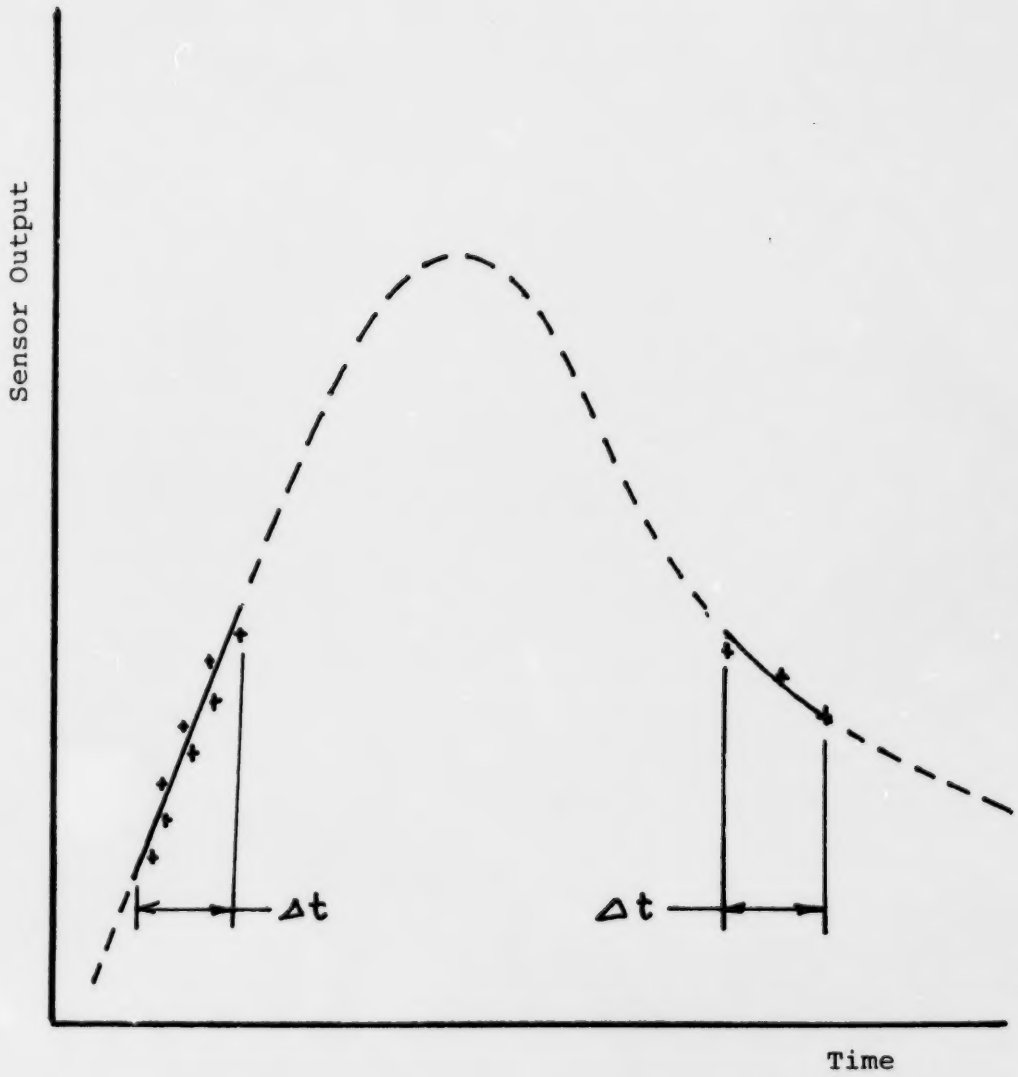


Figure 2. Curve Fitting



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